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EFFECTS OF REINFORCER DELAYS ON CHOICE AS A FUNCTION OF INCOME LEVEL

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Three rats earned their daily food ration by responding during individual trials either on a lever that delivered one food pellet immediately or on a second lever that delivered three pellets after a delay that was continuously adjusted to ensure substantial responding to both alternatives. Choice of the delayed reinforcer increased when the number of trials per session was reduced. This result suggests that models seeking closure on choice effects must include a parameter reflecting how preference changes with sessionwide income. Moreover, models positing that reinforcer probability and immediacy (1/delay) function equivalently in choice are called into question by the finding that probability and immediacy produce opposing effects when income level is changed.

Key words: choice, reinforcer delay, income level, economics, lever press, rats

Rachlin, Logue, Gibbon, and Frankel (1986) developed a procedure for studying repeated gambles in humans. In their experiment, subjects chose one of two disks, each of which was composed of 18 equal-sized, wedge-shaped sectors. The left disk ("the sure thing") was composed of 17 white sectors and one black sector, whereas the right disk ("the risky gamble") was initially composed of seven white and 11 black sectors. When a subject chose a disk, a pointer above that disk was spun. If it stopped over a white sector of the selected disk, the subject "won," whereas no payoff was provided when a pointer stopped over a black sector. Winning "the sure thing" resulted in a hypothetical $100 payoff, and winning "the risky gamble" produced a hypothetical $250 payoff. Rachlin et al. (1986) found that the longer the time between successive choices (regulated by an intertrial interval or ITI), the greater the tendency to choose the sure thing.

Silberberg, Murray, Christensen, and Asano (1988) attributed these results to subjects having an implicit idea of how long an experiment would last that was independent of ITI duration. As a consequence, subjects who had short ITIs thought they would have many trials over which to earn money, while those with long ITIs thought they would have only a few trials. This made those who perceived themselves to be in the "few-trial" condition behave conservatively, favoring the sure thing. On the other hand, those subjects who thought they would have many trials often chose the risky gamble because they thought they could earn substantial money despite a short-term run of bad luck. Thus, the ITI effect reported by Rachlin et al. (1986) was viewed as due to trial density changing subjects' perceptions of how much they would earn in a session.

Economists have long noted that a change in income often affects demand for goods unequally (Deaton & Muellbauer, 1980). Silberberg et al. (1988) hypothesized that such an income effect could explain the findings of Rachlin et al. (1986). Evidence consistent with this view comes from a recent nonhuman analogue of the repeated-gambles procedure (Hastjarjo, Silberberg, & Hursh, 1990b). In this study, rats earned their daily food ration by choosing, during individual trials, between one lever that provided three pellets with $p = 1.0$ and another lever that provided 15 pellets with $p = .33$ (no pellets otherwise). Income level was manipulated by varying the number of trials per session across conditions. Hastjarjo et al. (1990b) found that when the number of trials per session was reduced, subjects' preference for the certain alternative increased. In other words, choice of the risky outcome was, once again, correlated with income level.

In both the Silberberg et al. (1988) and Hastjarjo et al. (1990b) studies, subjects responded to a drop in income by ensuring some return for each choice rather than maximizing the total sessionwide income. These results join

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those of Hastjarjo, Silberberg, and Hursh (1990a) in demonstrating that aggregate income in a session has a powerful effect on choice even when other parameters of reinforcement (e.g., rate, delay, and amount) are left unaltered. The present experiment tests whether this income effect (i.e., number of trials per session) generalizes to a setting involving choice between a small food reinforcer delivered immediately and a larger reinforcer delivered after a delay.

METHOD

Subjects. Three experimentally naive adult male rats (Subjects 5, 6, and 7), deprived to 85% of their free-feeding weights, served as subjects. They were maintained in individual cages where water, but not food, was available.

Apparatus. The experiment was conducted in an experimental chamber (30 cm by 25 cm by 29 cm) (Coulbourn Instruments Model E10-10F) that was housed in a larger sound-insulated box. Two levers (3.5 cm wide) were positioned on the front wall 19 cm apart and 6.5 cm above the grid floor. Both response levers required a force of 0.25 N to operate. A 28-V stimulus light was located 4 cm above each lever. Food reinforcers (45-mg pellets from Bioserv) were delivered into a food tray centered between the two levers 2 cm above the floor. A 28-V houselight was mounted 25 cm above the food tray. Water was continuously available from a bottle mounted on the Plexiglas side wall. A microcomputer controlled all contingencies and recorded data.

Procedure. After lever-press training by the method of successive approximations, each subject was exposed to the main experimental procedure in which it earned its daily food ration. A session consisted of a number of forced- and free-choice trials that varied across experimental conditions. In each session, two forced-choice trials preceded a block of 20 free-choice trials. During a forced-choice trial, only one lever was selected as correct, a circumstance signaled by illuminating the light above that lever. Selection of the signaled lever was random, with the constraint that the left and right lever each was selected once during each pair of forced-choice trials. Responding to the unsignaled lever had no scheduled consequences, whereas selection of the signaled lever resulted in the delivery of its associated reinforcer. Free-choice trials were distinguished from forced-choice trials in that during the former both lever lights were illuminated and both levers were functional. If, during a free-choice trial, the subject responded on the lever correlated with the immediate delivery of one food pellet, the houselight and the lever light were simultaneously darkened, and the light over the food cup was illuminated. Pressing the other lever was correlated with the delayed delivery of three pellets. A response here turned off the lever light, turned on the houselight, and initiated a delay period. After the delay, the houselight was turned off, the food-cup light was illuminated, and three pellets were delivered. Regardless of the lever selected, delivery of the last food pellet turned off the food-cup light and illuminated the houselight, beginning a 20-s ITI. Assignment of the left or right lever to immediate or delayed reinforcement was balanced across subjects.

A titration procedure controlled the duration of the delay to the larger reinforcer. If, during a five-trial block, all responses were to the lever associated with the larger reinforcer, its delay was increased by 1 s. Alternatively, if all choices during the five-trial block were to the immediate-reinforcer lever, the delay was decreased by 1 s. As long as each lever received at least one response during a five-trial block, the delay was left unchanged. At the beginning of each condition, the delay to the larger reinforcer was arbitrarily set at 10 s for all subjects. For subsequent sessions within a condition, sessions began with the delay value in use at the end of the prior session.

Income level was manipulated by varying the number of free-choice trials per session. In high-income conditions (Conditions 1 and 3), rats were given 100 free-choice trials. In the low-income condition (Condition 2), the number of free-choice trials equaled one third of the average number of pellets earned during the free-choice trials of each of the last five sessions of Condition 1.

Conditions changed when, in the experimenter's judgment, choice ratios were stable. Except where noted, all data analysis is based on the last five sessions of each condition.

Table 1 presents the order of conditions, the number of sessions per condition, the number of free-choice trials per session, and the lever assignment of the larger delayed reinforcer in each condition.

RESULTS

Figure 1 presents for each subject the mean choice proportion for the delayed reinforcer averaged across blocks of three sessions for each condition. In the first two phases of the study, no consistent across-session trends in preference were discerned. In the last phase, there was a tendency for preference for the delayed alternative to diminish across sessions.

Figure 2 presents for each subject the choice proportions for the lever associated with the larger delayed reinforcer during the last five sessions of each income condition. This proportion was obtained by dividing the frequency of delayed-lever choices by total choices. For all subjects, delayed-lever choices increased when reinforcement level decreased.

Because titrated delay values depended on the order of choices rather than on choice ratios, they also could serve as a separate index of the effects of trials per session on performance. These data are shown in Figure 3, which presents for each subject the duration of the titrated delay to the larger reinforcer averaged over the last five sessions of each condition. Except for Subject 6 in Condition 3, this delay was greater when income was low than when it was high.

Figure 4 presents for each subject the cumulative frequency of choice of the delayed outcome as a function of the cumulative frequency of choice of the immediate outcome. The expansion paths followed by these functions define how choice patterning changed throughout the average session during the last five sessions of each phase. For Rat 5, choice proportions were approximately constant during the first two thirds of a session whether income was high or low. Thereafter, preference for the delayed alternative increased. Except for the first 30 or so choices, choice of the delayed alternative for Rats 6 and 7 was consistently higher in the low-income condition than in the high-income conditions.

Figure 5 presents each subject's body weight on the last day of each condition. Open circles represent body weights during the high-income conditions, and filled circles represent body weights during the low-income condition.

Table 1

Subject number, order of conditions, sessions per condition, free-choice trials per session, and side lever to which delayed outcome was assigned in each condition of the experiment.

Subject	Condition	Number of sessions	Number of free-choice trials per session	Delayed lever
5	1	21	100	Left
	2	30	66	Left
	3	29	100	Left
6	1	23	100	Left
	2	22	63	Left
	3	20	100	Left
7	1	23	100	Right
	2	30	69	Right
	3	20	100	Right

For all subjects, body weights were lowest during the low-income condition, and only partially recovered when returned to the high-income condition in Condition 3.

DISCUSSION

In this study, preference for the larger delayed outcome increased when the number of trials per session decreased. This result was obtained even though other parameters of reinforcement, such as its rate, amount, and delay, were not changed across conditions. This outcome suggests that trials per session is an important variable in choice. If this attribution is correct, these results join others (Hastjarjo et al., 1990a, 1990b; Shurtleff, Warren-Boulton, & Silberberg, 1987; Silberberg, Warren-Boulton, & Asano, 1987) in demonstrating that a complete model of choice must represent not only the effects of reinforcer rates, delays, and amounts on choice but also the sessionwide income these parameters of reinforcement provide.

This interpretation is, of course, conditional on trials per session being the factor determining changes in preference in this study. There is a second possibility; the changes in body weight that attended manipulation of trials per session may have caused changes in choice. According to this view, subjects increased their preference for the larger delayed alternative when trials per session were re-

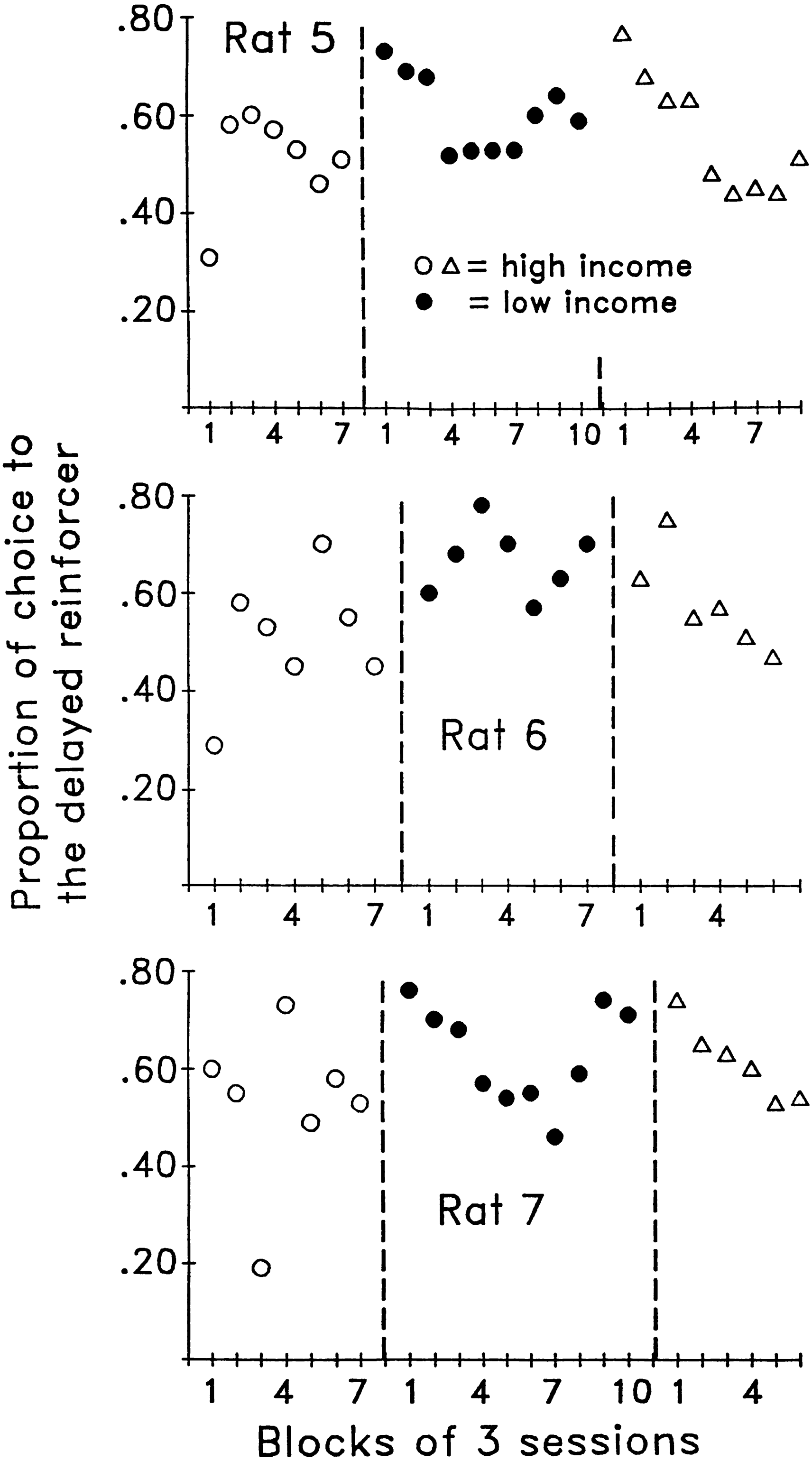

Fig. 1. Proportion of choice of the delayed alternative as a function of sessions averaged over three-session blocks for each subject in each condition.

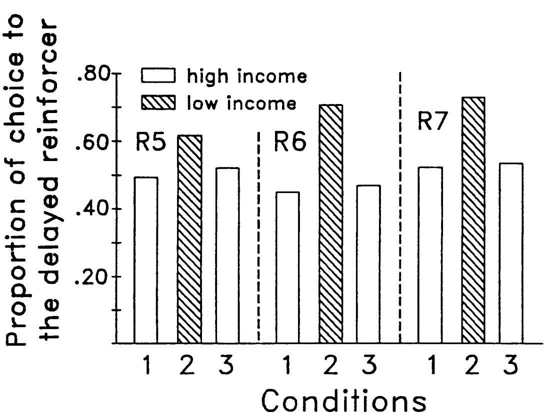

Fig. 2. Proportion of choices to the larger delayed reinforcer for each subject averaged over the last five sessions of each condition.

duced because of increases in their deprivation levels.

Even if this study's results can be attributed to a deprivation or body-weight effect, their relevance to the literature on delay of reinforcement and self-control is undiminished, because the usual finding is that increases in deprivation and decreases in weight do not result in increased choice of delayed alternatives (e.g., Logue, Chavarro, Rachlin, & Reeder, 1988; Logue & Peña-Correal, 1985). Clearly, the results of the present study are an exception to this generalization.

One way to determine the degree to which body weight and trials per session contributed to changes in preference is by comparing performances across conditions. The reduction in trials per session from Condition 1 to Condition 2 led, in Condition 2, to a significant reduction in body weight and a significant increase of choice for the larger delayed alternative. By itself, this comparison is confounded because changes in body weight and trials per session preceded changes in choice. This confounding effect can be resolved to some degree by comparing Conditions 1 and 3. In Condition 3, body weights were still significantly lower than in Condition 1 even though these conditions had the same number of trials per session. In this circumstance, preferences for the delayed alternative in Condition 3 did not increase significantly from levels obtained in Condition 1 (all tests [one-tailed Mann-Whitney U] based on the last five sessions of

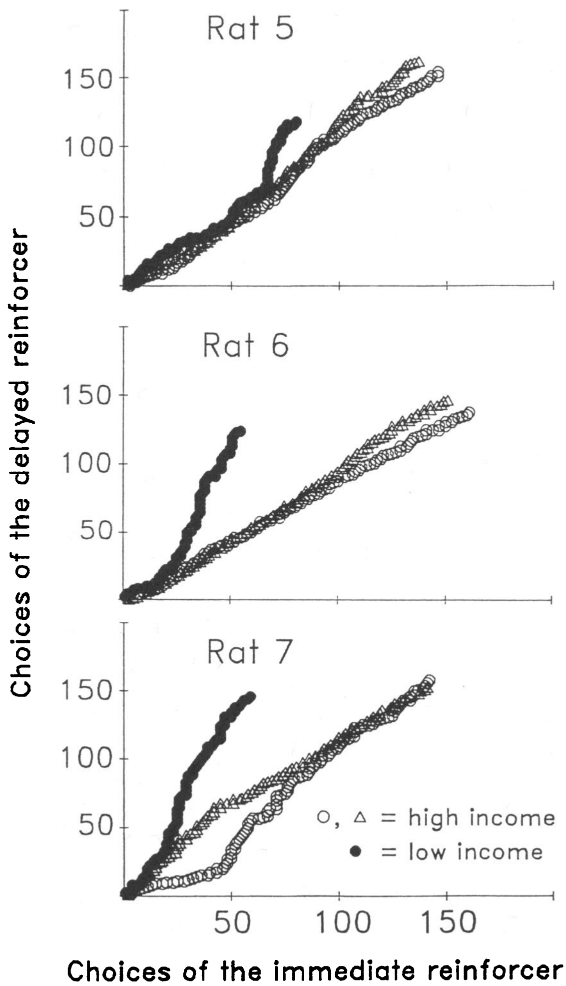

Fig. 4. Cumulative frequency of choice of the delayed outcome as a function of the cumulative frequency of choice of the immediate outcome for each subject averaged over the last five sessions of each condition.

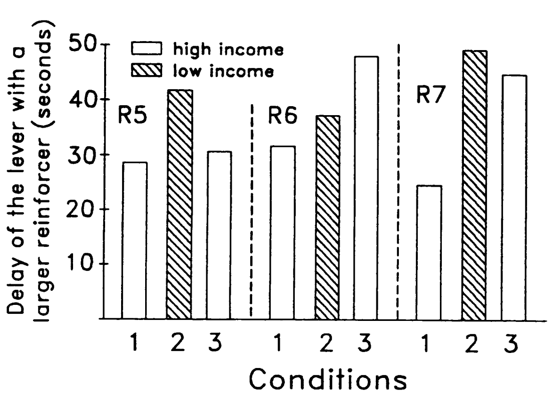

Fig. 3. Delay to the larger reinforcer for each subject averaged over the last five sessions of each condition.

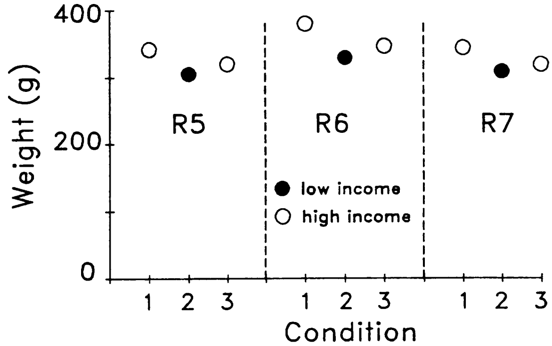

Fig. 5. Each rat's body weight in grams before the last session of each condition.

a condition with $p < .05$ defining a significant difference). These results are consistent with the view that body weight was less important than trials per session in controlling choice in this study.

These arguments notwithstanding, the present experiment cannot quantify the relative roles of body weight and trials per session in producing the results obtained. Such data require a new experiment in which body weights are held constant across conditions while trials per session are manipulated. With these results in hand, it would be possible to compare the relative contribution of these two variables to changes in choice when only income level is manipulated (the present study) and when only body weight is manipulated (proposed experiment).

No matter where one stands on the issue of what caused choice to change in the present experiment, these data have important implications for operant models of choice (e.g., see Williams, 1988). With few, if any, exceptions, these models ignore the effects of either body weight or across-session income in choice effects. Without parameters to reflect the operation of such variables, these accounts will be incomplete.

The results of the present report also bear on recent arguments that manipulations of immediacy (1/delay) and probability of reinforcement do not differ in their effects on choice (e.g., Rachlin et al., 1986). The Rachlin et al. model recognizes that in many concurrent procedures, rate, probability, and immediacy of reinforcement are not independent of one another. For example, when the rate of reinforcement on an intermittent schedule is doubled, the delay between each response and the series of reinforcers that follow as the session progresses is cut in half; if one assumes that rate of responding is unaffected by this manipulation, the probability of a response resulting in reinforcement is doubled.

This high degree of interdependence among variables permits reformulations of choice in which one variable subsumes others. Rachlin et al.'s (1986) equation of rate and immediacy of reinforcement is not the first step in this direction. Other choice models acknowledge that the dependence between these variables permits attributing the control of choice not to the rate at which reinforcers are delivered (e.g., Herrnstein, 1961), but to between-alternative differences in the delays produced between choices and the reinforcers they provide (e.g., Mazur, Snyderman, & Coe, 1985; McDiarmid & Rilling, 1965).

The results of the present report, when considered with those of Hastjarjo et al. (1990b), call these exercises into question by demonstrating a context in which delay and probability of reinforcement operate in ways that seem opposite. In the present report, reductions in income level decreased choice for the more immediate alternative. Based on Rachlin et al.'s (1986) idea that immediacy and probability function equivalently, one would expect income reduction to result in decreased preference for the higher probability alternative when one choice results in a large, probabilistic reinforcer and the other a small, certain one. Contrary to this prediction, Hastjarjo et al. (1990b) found that income reduction led to increased choice of the certain alternative over the probabilistic one. Given these opposite effects, how can a model claiming functional equivalence for probability and immediacy be complete? Clearly, the functional overlap among rate, delay, and probability variables is not absolute. For this reason, accounts of choice that maintain that these are independent variables affecting choice hold greater promise for offering a correct characterization of choice (see Navarick, 1987).

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